Plasma Tornadoes

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A sounding rocket that flew over a bright Alaskan aurora has observed what appear to be supersonic plasma tornadoes in space. Not just a single twister, but as many as 16 rows of individual vortexes were traversed as the payload flew poleward across the aurora. Plasma wind velocities inside the row of tornadoes reached as high as 3,000 meters per second (6,500 miles per hour), at an altitude of about 500 to 550 kilometers, equal to the highest space shuttle orbits. At that altitude, the sound speed in the plasma is approximately 1,500 meters per second, making these twisters supersonic.

Development of the instrumented payload and analysis of the data were carried out by researchers at Cornell University, the University of New Hampshire, and MSFC, each of whom contributed to the plasma or field instrumentation. An understanding of the data has come from a lengthy analysis, which was complicated by the spin and "coning," or precession, of the payload as it sailed through space over the aurora.

Apparent tornadic flows in auroras have been previously reported by ground observers and recorded through low-light level television imagery of auroral dynamics by cameras on the ground. To see the vortex-like motions, it is best to view the aurora nearly overhead but slightly toward the equator so as to view directly along the local magnetic field lines. Fluctuations in the brightness of the auroral light display are then seen to move in a circular fashion around bright spots in the aurora that appear as bright rays from more oblique perspectives. The location and spin rate of the vortexes are usually highly variable, though often well-organized into an extended bright row that has a drapery-like appearance.

The rocket observations are the first to indicate that the apparent vortical motions in the television imagery are real plasma flows. Previous rocket payloads have provided ample evidence of strong and highly variable plasma winds that can be observed directly as motions of the plasma relative to the rocket payload, or as variations of the electric field in the region around the payload, sensed by sensitive antennas deployed from the payload. All plasma winds in magnetic fields can be sensed this way because they produce a characteristic electric field. A vortical pattern of the variations has not previously been discovered in plasma flow or electric field data.

The vortical motions are perhaps best visualized by means of a plot of the horizontal wind vector as a function of position along the rocket ground track, as shown in figure 33. The region including the aurora spans three panels in this figure, which should be read from left to right and top to bottom. Before the payload enters the auroral region, the flow is relatively slow and directed generally equatorward (a headwind for the rocket). Entry into the aurora is marked by a large increase in the plasma flow vector, followed immediately by rotation of the plasma wind vector to the left (as seen in this view from above). The rate of rotation is irregular, but the sense of rotation is evidently monotonic.

Strong plasma heating is associated with the region of aurora and intense vorticity. All observed ion species were heated by a factor of approximately two in absolute temperature in the event shown in figure 33. Figure 34 shows the time series of measured plasma temperature for this event, indicating the auroral heating that was present. At present, it is not clear how the heating and the vortical motion are coupled. The high-speed plasma winds themselves are a possible source of heating, since the plasma probably flows through a permeating gas that is relatively stationary. The frictional interaction between the two is sufficient to produce significant heating of the heavier plasma ions. However, the observed heating of the heavier species is somewhat larger than can be accounted for by friction, and the heating of the light species is far in excess of that which can be produced by friction. Therefore, it is likely that the heating is enhanced by the highly structured vortical flows in some way, perhaps through the dissipation of the vorticity into turbulence that heats the plasma.

Auroral tornadoes probably have an origin very different from that of ground-level tornadoes, which get their energy from enhanced vertical motions of the atmosphere, driven by the release of latent heat during the condensation of water vapor, combined with the rotation of the Earth. In space, the vortexes are likely to "spin off" from jet stream-like channels of supersonic plasma flow that are driven by a direct coupling
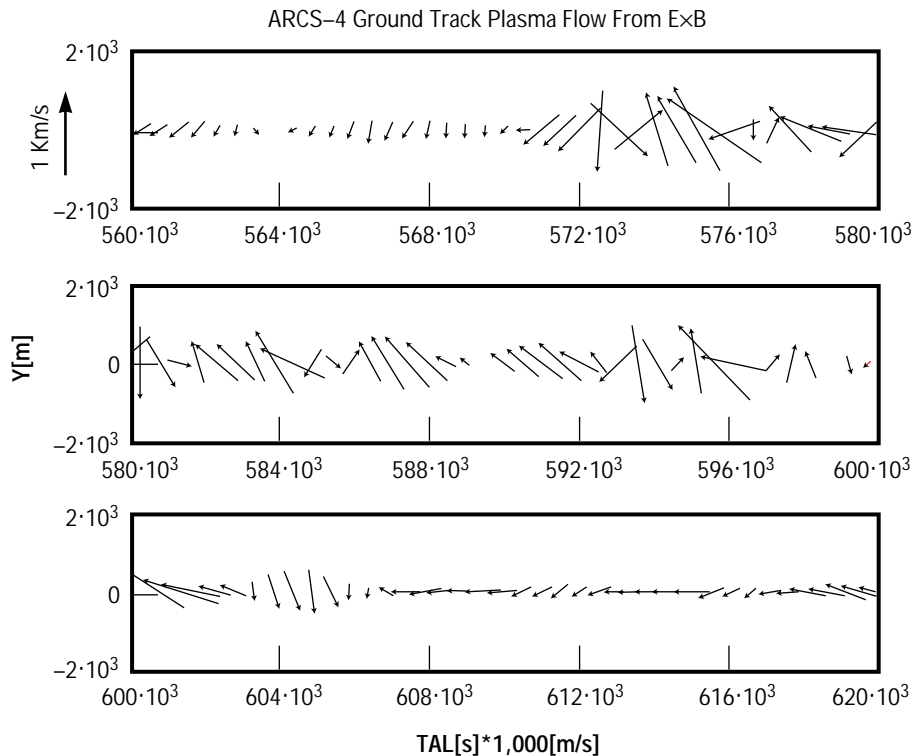
ARCS–4 Ground Track Plasma Flow From E×B

F𝚒𝚐𝚞𝚛𝚎 33.—Ground track display of the horizontal plasma-velocity vectors recorded at 0.5-second intervals over an auroral display. The ground track proceeds from left to right and top to bottom through the three panels of the figure, as the payload moves poleward across the aurora.

between the auroral plasma and the solar wind, which passes the Earth at speeds up to 400,000 meters per second (1,000,000 miles per hour). The Earth's magnetic field transmits the solar wind motion and energy to the aurora, creating a region of intense shear that leads to development of multiple vortexes. The plasma heating is probably a by-product of the process rather than a driver of it, as in the case of tropospheric tornadoes.

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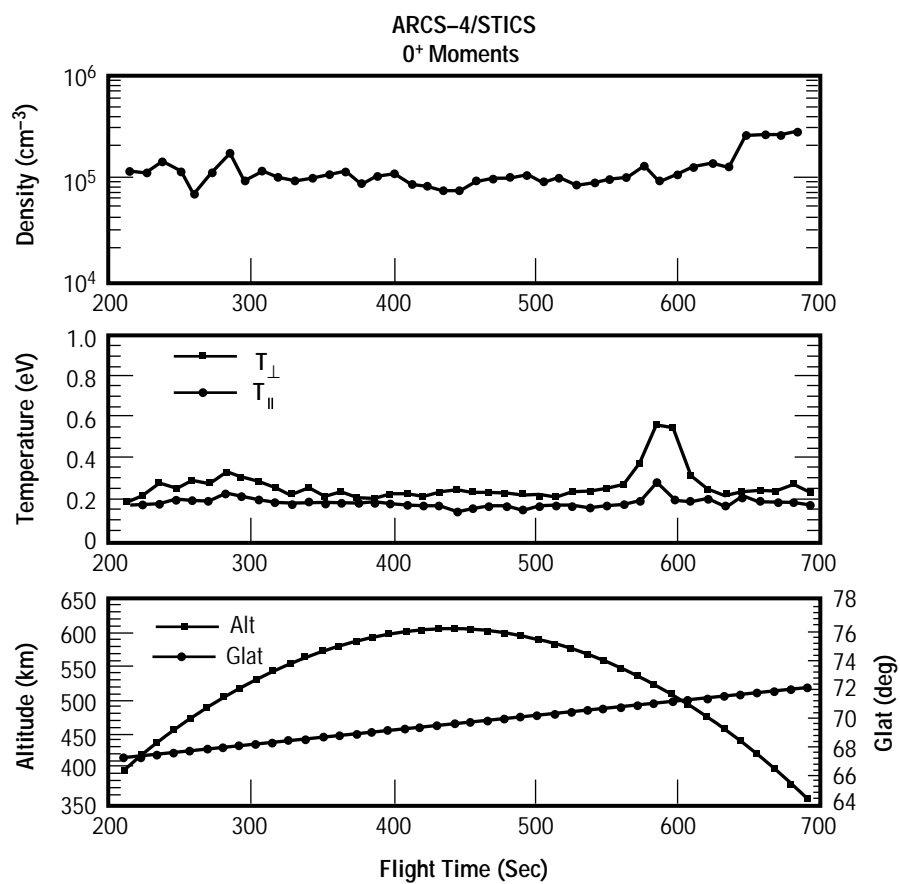
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ARCS–4/STICS
0⁺ Moments

FIGURE 34.—Temperatures of the oxygen ions as a function of flight time and ground track position over an auroral display.